Study of Plant Communication to Analyze Stress and to Predict Pest Infestation Using Artificial Neural Networks

A synopsis of the proposed thesis to be submitted for the degree of

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INTRODUCTION:

Agricultural production has a major contribution to GDP growth of India. According to economic survey 2018, 58% of indian population is employed in agriculture, which contributes 17-18% to GDP [1]. This is a big contribution, however, it is challenged by some factors. One of them being pest infestation. Pest infestation poses a threat to agricultural production in several developing, as well as developed countries. 28.2% loss of wheat, 37.4% loss in rice, 31.2% loss of maize and 40.3% loss of potatoes has been reported worldwide due to pest infestation [2]. Indian economy suffers an approximated annual loss of Rs. 2,750 billion because of pest infestation [3]. Despite several pest control measures being available, Indian farmers mainly rely upon the chemical methods to control the pest infestation. These chemicals are named differently under the umbrella of pesticides, depending on their function eg. chemicals to control insects are called insecticides, chemicals to control unwanted growth of herbs are called herbicides. Because of the lack of knowledge of how to use pesticides, farmers misuse or overuse these chemicals. This further gives rise to other problems such as pesticide poisoning, environment pollution etc. [4].

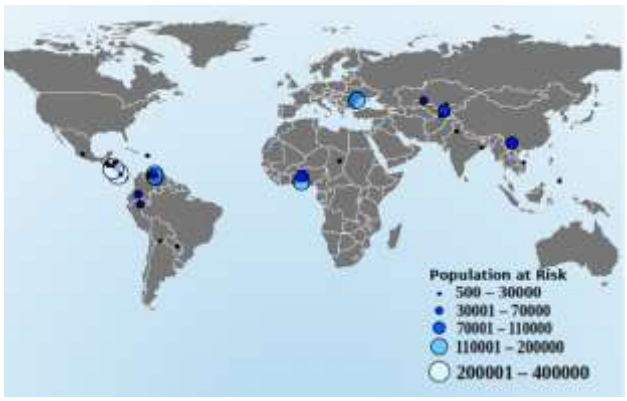

Figure 1: Population at risk because of pesticides[44]

Figure 2: Skin problems caused by pesticides[44]

Not only these chemicals mutate the insect pests and stop further working on them, but also lay a firm foundation for the threats like water pollution, air pollution, food poisoning and health hazards for the person spraying these chemicals [5]. According to WHO, pesticides are the leading cause of self poisoning in low- and middle-income countries, some chemicals (eg. DDT and lindane) were so harmful, these have even been banned (Stockholm Convention, 2001). The toxicity of pesticides depend upon their function and other factors. Insecticides have been reported as much toxic than

herbicides, their different exposure to someone can lead to different consequences [6]. Furthermore, chronic exposure to pesticides can severely affect skin, eyes, nervous system, cardiovascular system, liver, kidneys and can even cause cancer. Moreover, children are more vulnerable to the effects of pesticides because of greater exposure (milligram of pesticide per kilogram body weight) [7]. WHO reported, death toll due to pesticide poisoning was 186,000 in 2002 alone, which is just the tip of the iceberg [8]. Furthermore, studies in developed countries show, 18.2 per 100,000 full time agricultural workers and 7.4 per million school children face acute pesticide poisoning (APP), which makes this a global problem [10]. Moreover, in some countries like China and Sri Lanka, self-poisoning with pesticides is a particular problem [11]. APP incidence rate of approximately 180 per 100,000 has been reported in Sri Lanka [12].

United Nations Population Division expects that by 2050, population of world would reach 9.8 billion, 30% more people compared to today. Most of this population growth is going to happen in developing countries [13]. Furthermore, crop production has to be increased to cope up with the increasing population. According to Food and Agriculture Organization of the United Nations (FAO), 80% increase in crop production can be achieved from increase in yield and number of times a crop is produced in a year and only 20% can be increased from expanding the possible crop land [14]. It's a no-brainer that crop loss has to be minimised to achieve better yields.

So in conclusion, not only pest infestation but also the pesticides are our problem. Pest infestation can damage the crop before it grows and pesticides can degrade the quality of crop even if it grows. So, what if a system could detect the pest infestation even before it proliferates?

Artificial Neural Networks (ANN) is a technique which has got a lot of attention recently, because of its huge applicability in forecasting of weather, finance, stock prices etc. This technique mimics the human brain and its working. A neural network is a combination of several neurons, which have entry points for signals with some amplification factor called as weight. When ANN is trained these weight values are adjusted, so to produce a desired output value [38, 39]. After the training, prediction can start, when different inputs are applied.

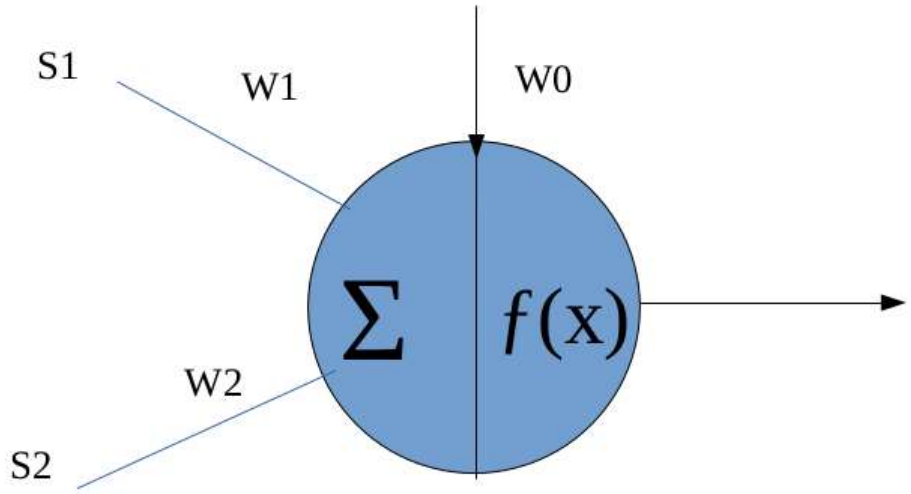

Figure 3 : An Artificial Neuron

MOTIVATION:

It has been reported that approximately 70% farmers worldwide have less than a hectare of farm [45], which makes reducing the crop loss an absolute necessity. Furthermore, according to a survey, in US average time spent by farmers on farming activities is more than 10 hours per day [32]. This can be more in developing countries like India, given the status *quo*. Even after putting this much effort, good yield is not guaranteed. Department of Agriculture Cooperation & Farmers Welfare reports, the average income of an Indian farmer from July 2012 to June 2013 was as low as Rs. 6,426 against average monthly consumption of Rs. 6,223. Furthermore, 22.5% farmers were living under poverty line, and then, problems like crop loss just act as cherry on top.

With a reported population of 1.21 billion in census 2011, India is the second largest country in the world after China [19]. More than half of this population is employed in farming activities, which help India in becoming world's largest producer of pulses and jute as well as second largest producer of rice, wheat, sugarcane, groundnut, vegetables, fruit and cotton [18]. Furthermore, gross value added by agriculture, forestry and fishing was estimated at Rs. 19,196 billion in financial year 2018 [15], although, a loss of Rs. 2750 billion was suffered because of pest infestation. Therefore, should crop health brought under the focus, the gross added value can be increased.

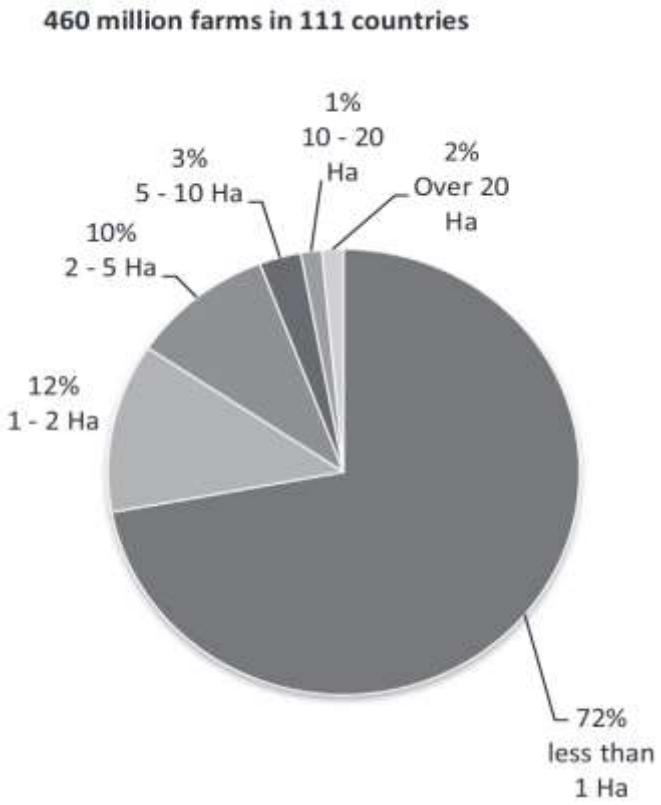

Figure 4: Share of farms worldwide [45].

Humans show signs like fever before actually suffering from a disease. This behaviour is also found in plants. It has been seen that plants start to produce phenol derivatives [20], when they are attacked by insect pests. What if, this production of phenol derivatives could be detected much earlier so that the adverse effects of pest infestation could be averted. When I studied about neural networks, it all seemed possible. Neural network is a data driven technique and is currently being used for weather forecasting, financial forecasting, image recognition etc. Since, it depends on the data, with increasing data the accuracy of prediction becomes quite better. Putting this technique for the prediction of pest infestation would make an interesting study.

LITERATURE REVIEW:

On the basis of requirement by the plants, soil nutrients are divided in *macro-* and *micro-nutrients.* Macro-nutrients, which include Nitrogen (N), Phosphorous (P), Potassium (K) etc., or NPK in short, are required by the plants in large quantities. While micro-nutrients, which include Boron (B), Iron (Fe), Manganese (Mn), Zinc (Zn) etc., are required in smaller quantities, however, are essential for the development. For a better plant growth, availability of these nutrients is required in area upto ~2 mm

(rhizosphere) away from plant roots [41]. Plants require macro-nutrients in relatively large quantities (more than 0.1% of dry mass) and are essential for the plants to complete their life cycle. K, Ca and Mg are taken in ionic form [43], while nutrients with negative electron affinity are taken in oxyanionic form (PO_4^{3-}, NO_3^- etc.) [42].

In my M.Sc., we hypothesised, if plants use macro-neutrients in ionic and oxyanionic forms for most of their life, these must be the elements, which decide the pH of the soil. Therefore, should a neural network be trained for predicting the amounts of these elements from pH of acid-base mixed solutions (with known concentrations), the amount of these elements can be predicted using this network (even in the soil), however, accuracy of prediction can be increased using more input parameters (like voltage and current). Furthermore, a warning trigger can also be sent, if this amount decreases below a threshold value which would indicate some stress is acting on the plants.

Stresses are the parameters which change drastically and affect overall crop plant health, be it non-living (abiotic) or living (biotic) factors [20]. Pest infestation is a kind of biotic stress. It has been reported that K-defficient plants were more susceptible to pest infestation than those with adequate supply of K [27]. Furthermore, a review of 2449 references shows that use of K significantly decreased the fungal diseases by 70%, bacteria by 69% and insects and mites by 63%. Adequate amount of K increases the concentration of phenolic compounds in plants, which plays a critical role in plant resistance towards biotic stress [28]. According to some studies, plants also try to send the warning signs to nearby plants [22], when stressed abiotically or biotically. Furthermore, this signalling can happen either via air with volatile organic compounds (VOCs) [23] or via roots with common mycelial networks (CMNs) [24].

Currently, remote sensing techniques are widely applied in detection and monitoring of pest infestation in forests [29], a field based bark beetle monitoring program is implemented in Germany [31]. In this study, remote sensing data was acquired from RapidEye and TerraSAR-X and was analyzed separately with three different algorithms (*generalised linear models*, *maximum entropy* and *random forest*) for distinguishing the healthy areas from bark beetle affected areas [30]. It has also been reported that, Oaks when infested with splendour beetle (*Agrilus biguttatus*) show high levels of defoliation and altered canopy reflection signature, which can be easily identified and analyzed with high-resolution

colour infrared (CIR) and near infrared (NIR) images taken with the help of high flying aircraft [33], however, implementation of these techniques can be expensive. Furthermore, satellite imagery may not be clear, if clouds are present. Moreover, the data provided will be large in size because of the high resolution, therefore, hard to analyze.

These remote sensing techniques use artificial neural networks (ANNs) for image recognition [37]. Earlier in 1990s, ANNs had been used for financial forecasting, rain-fall forecasting etc [34, 35, 38]. Use of convolutional neural networks (convnets, a modified ANN) has recently become a trend in smartphones for face unlocking purposes [36]. Convnets are very deep neural networks with an excellent error rate (about 16.4%), because of which these had shown a decent performance in classification of hand-written digits and face detection [40]. Convnets might have a marvelous ability for image classification, however, if this ability could be extended to forecasting, it can do wonders.

OBJECTIVE:

The goal of the proposed research work is to predict the occurrence of pest infestation in different parts of crop field, for an early detection and mitigation. Following points will be brought under focus:

- Understanding the stress response in terms of voltage-current characteristics, relating it to plant physiological parameters like ion exchange, nutrient uptake.
- Development of distributed sensor network to analyse the change in soil properties under stressed and normal conditions of plant. Relating these soil properties to the VI characteristics of plant.
- Bio-inspired systems modeling (NN/AI) and creation of backend logic, capable of identifying different patterns using the above data to analyse stress.
- Modelling an automated data collection and analysis hub, which forecasts the probability of occurrence of pest infestation in different parts of a region.

METHODOLOGY:

- The conductivity of soil depends upon the number of ions present in it. Moreover, with the help of Voltage-Current characteristics and power transferred through soil, the values of the ions can be calculated. Soil pH can also be a good indicator for calculating the amount of soil nutrients. pH value of above 7 or below 7 may indicate towards the polarity of ions present in the soil in majority.

  VOCs may also be having a chemical signature in light spectrum, which can be detected using some methods like near infrared spectroscopy or FTIR technique [33].

- For backend algorithm, neural network based techniques will be used. These techniques had been used for financial forecasting, traffic forecasting etc. and were quite successful in these areas [38]. Currently, neural networks are being used as pattern recognition and face recognition backends for unlocking mobile phones [36]. Identification of patterns in data is underlying property of neural networks, which can be exploited to recognise the patterns in pH changes, voltage changes or VOC signature changes in light spectrum.

- Implementation of backend algorithm and design of experimental setups will require software platforms. For 3D modeling of experimental setups, we are going to use Blender and Autodesk Fusion 360. For testing, debugging and implementation of backend algorithms, we are going to use GNU Octave (similar to MATLAB but open sourced) and Python3. For hardware implementation of different sensors Raspberry Pi, Arduino UNO and NodeMCU will extensively be used.

	0 – 4 Months	4 – 8 Months	8 – 12 Months
1st Year	Literature Survey, Problem statement	Feasibility analysis and proof of concept	V-I characteristics experiment for plants under stress & data analysis.
2nd Year	Variable frequency analysis of soil samples & data analysis	Analysis of VOCs in NIR or Microwave region.	Coding of backend logic for identification of different patterns.
3rd Year	Designing of a multiplex sensor capable of automating all analysis.	Field testing of designed sensor and logic.	Writing and final submission of PhD thesis.

OUTCOMES:

With every rise of 2° C in global surface temperature, pest infestation increases by an average 32%, that makes pest infestation an imminent threat with rising global warming [46]. Successful completion of this proposed research work would mitigate the crop loss of worth Rs. 2,750 billion per year due to pest infestation. Additionally, increase in crop production will lead to low crop prices, consequently, India can provide food for below poverty line population (30% of total population) at low cost. Furthermore, with known areas of pest infestation, use of pesticides can also be reduced, leading to less health hazard, water, air pollution etc.

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